Biomorphic Systems and Missions: Surface-Aerial Cooperative Exploration Strategies

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BIOINSPIRED ENGINEERING OF EXPLORATION SYSTEMS (BEES)

- DEFINITION: BIOMORPHIC EXPLORERS, BIOMORPHIC MISSIONS
- BACKGROUND: BEES 1998 and 2000
- BIOMORPHIC MISSION: COOPERATIVE LANDE/ROVER -BIOMORPHIC EXPLORERS MISSION
- BIO-INSPIRED LANDMARK/FEATURE RECOGNITION
  - ENABLING PROCESSOR FOR SURFACE FEATURE RECOGITION
  - BIOMORPHIC COMMUNICATION AND NAVIGATION
  - BIOMORPHIC COPERATIVE BEHAVIORS
- MISSION ROADMAP
  - MISSION TIME STEPS
  - POTENTIAL 2007 MISSION
- SCIENCE APPLICATIONS AND PAYOFF

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BIOMORPHIC EXPLORERS

- Bio-morphic explorers constitute a new paradigm in autonomous mobile systems that capture nature's success strategies to implement new capabilities, that enable new scientific endeavors.
- Bio-morphic explorers are a unique combination of versatile mobility utilizing adaptive, fault tolerant bioinspired sensory info processing, controls, navigation, communication and cooperative behaviors to autonomously explore the challenging unknown and un-trodden domains of space and earth.

BIOMORPHIC MISSIONS

- Biomorphic Missions are co-operative missions that make synergistic use of existing/ conventional surface and aerial assets along with biomorphic explorers.

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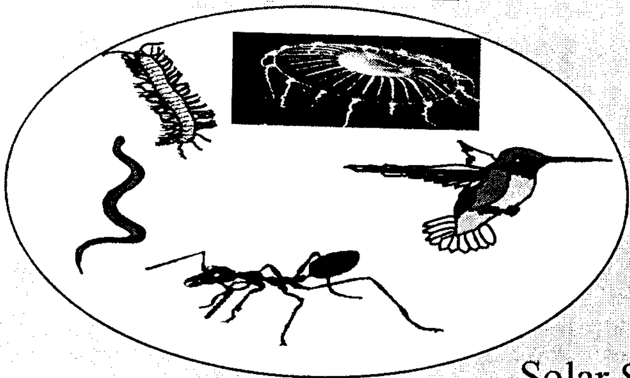
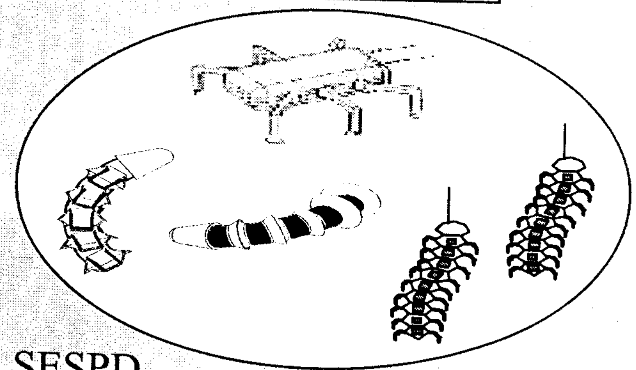
BIOINSPIRED ENGINEERING OF EXPLORATION SYSTEMS

1st NASA/JPL Workshop on Biomorphic Explorers for Future Missions

INSPIRATION

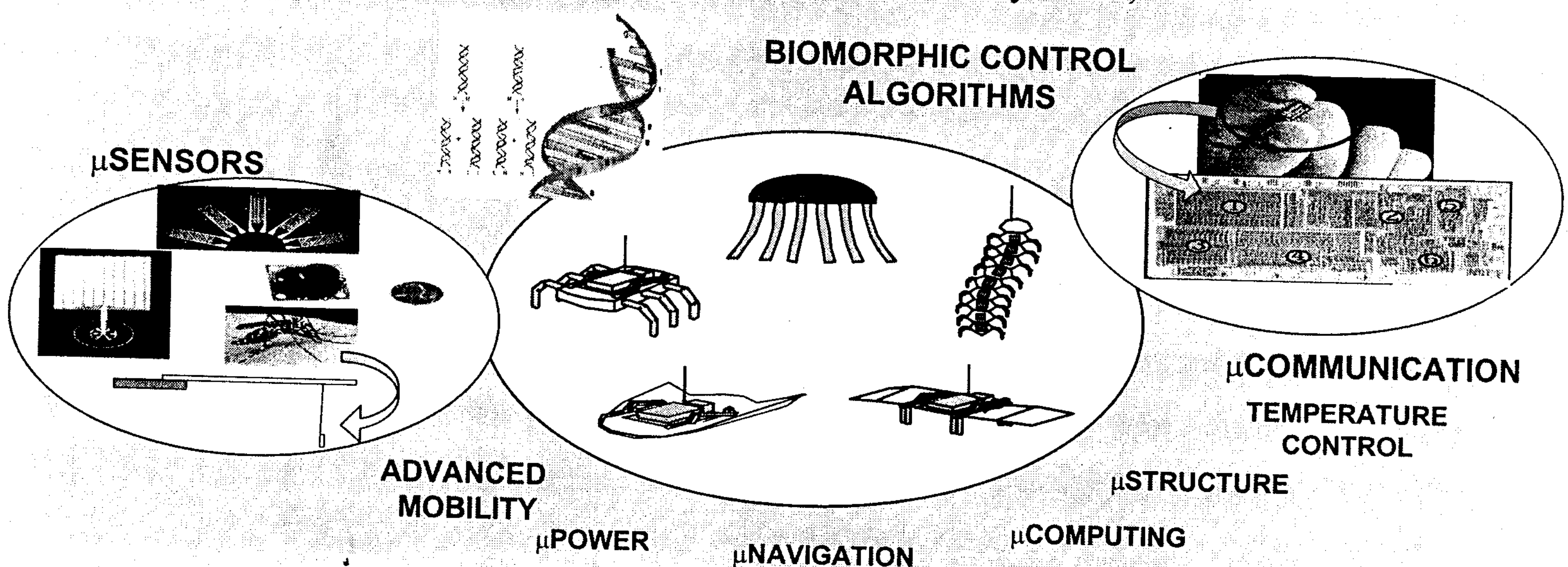


IMPLEMENTATION



August 19 - 20, 1998
Jet Propulsion Laboratory
Pasadena, CA
Auditorium 180 - 101

Sponsored by NASA/JPL
Solar System Exploration Program, SESPD
New Millennium Program, NMP
Space Mission Technology Development Program, TAP
Center for Integrated Space Microsystems, CISM



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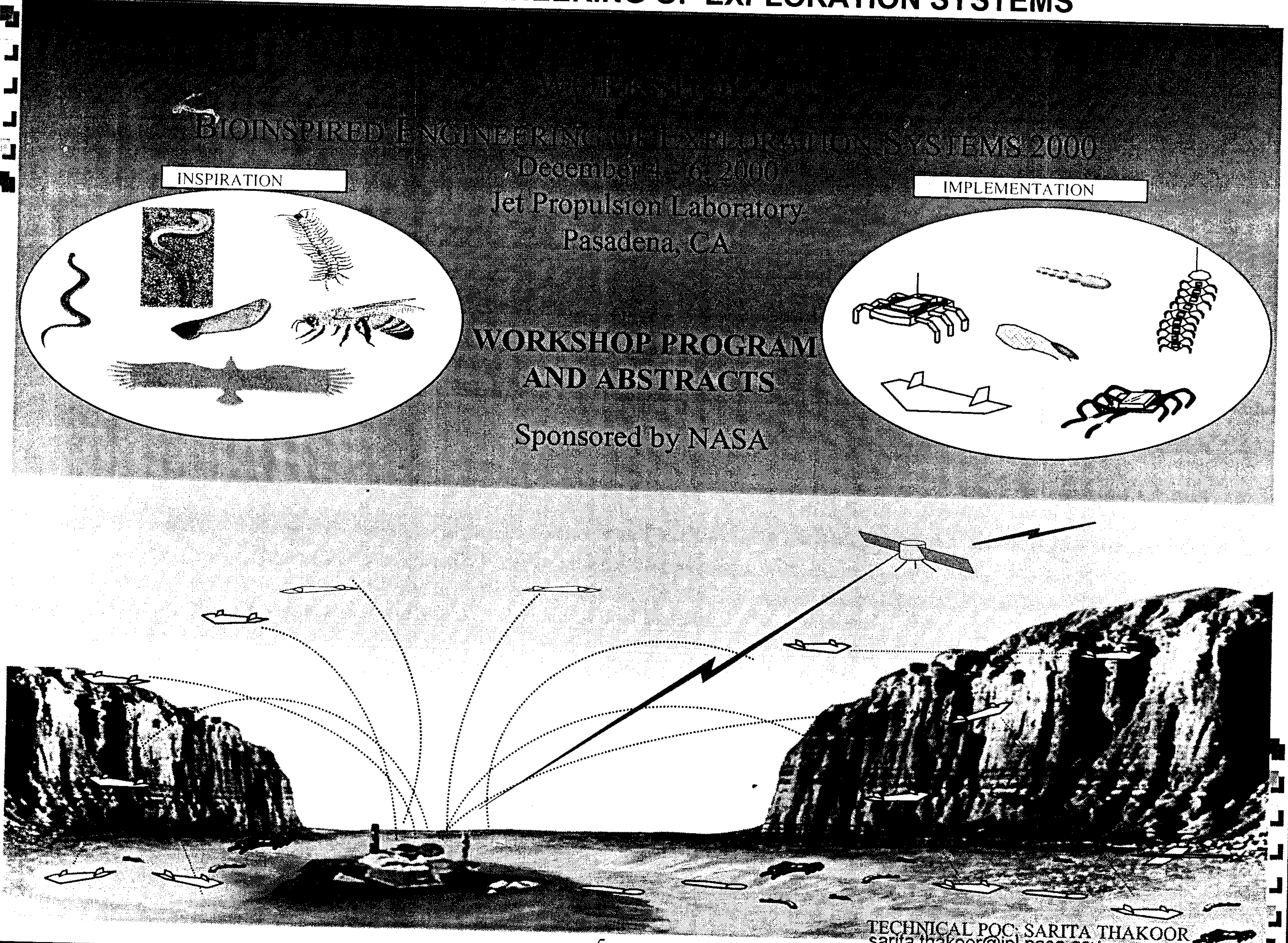
BIOINSPIRED ENGINEERING OF EXPLORATION SYSTEMS



Science Requirements

- Orbiter provides imaging perspective from ~ 400 Km height with resolution ~ 60 cm to 1 m/pixel; lander mast imagery is view from ~ 1-2 m height, the essential mid range 50m-1000m altitude perspective is as yet uncovered and is an essential science need. Imaging from this mid-range is required to obtain details of surface features/topography, particularly to identify hazards and slopes for a successful mission)
    - Close-up imagery of sites of interest (~ 5 - 10 cm resolution)
    - 1-10 Km range, wide area coverage
    - Distributed Measurements across the entire range
    - In-situ surface mineralogy.
- Candidate instruments include
    - Camera (hazard & slope identification by close-up imagery)
    - Meteorological suite (in-flight atmospheric measurements)
    - Microphone to hear surface sounds, wind and particle impact noises
    - Electrical Measurement of surface conductivity
    - Accelerometer Measurement of surface hardness
    - Seismic measurement (accelerometers)

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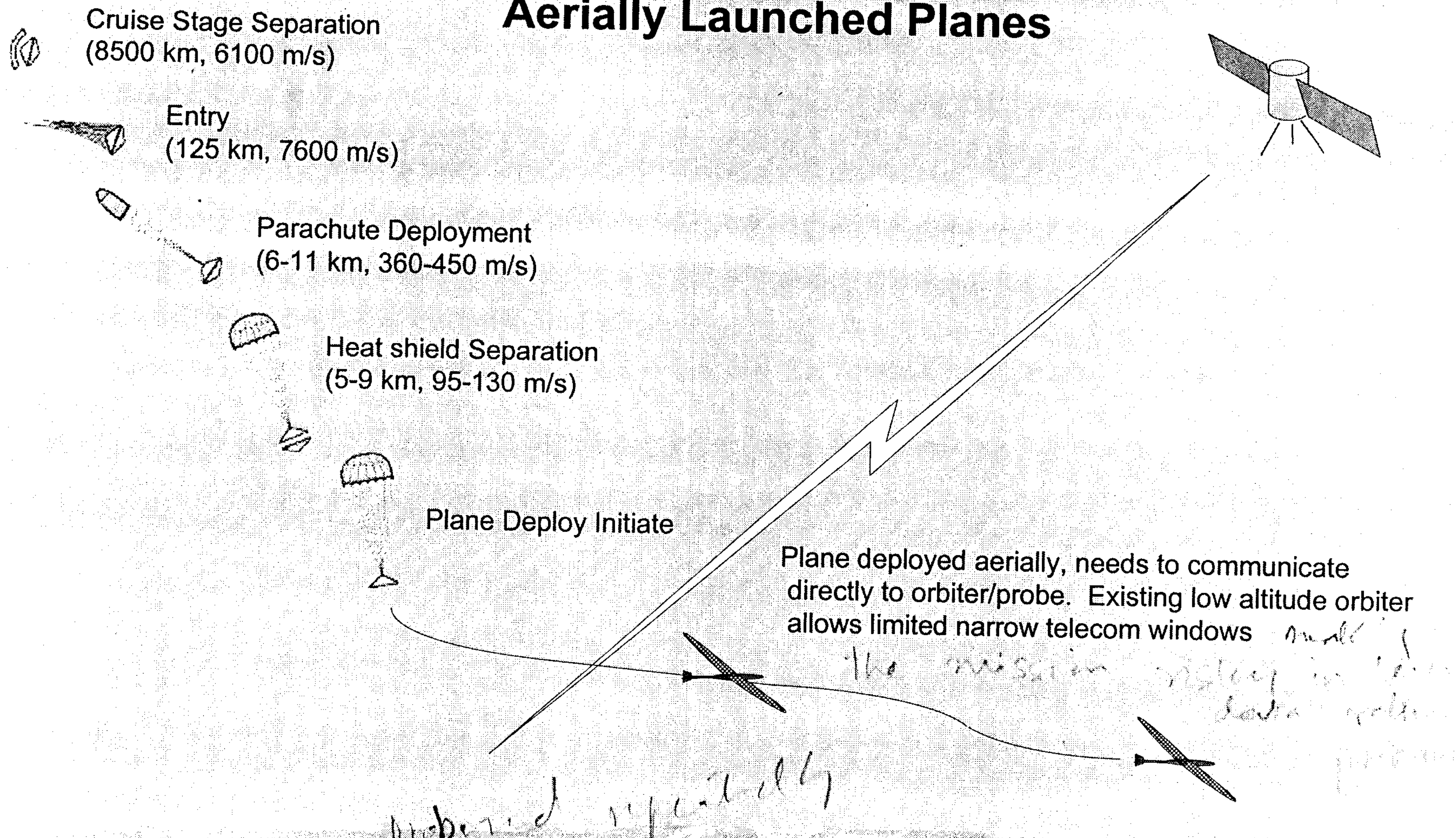
Aerially Launched Planes



The above scenario has been ~~thought about a lot~~ proposed repeatedly in the last few years. A high altitude Near Synchronous Orbit providing Long-Dwell service to any point on Mars is necessary/desirable for success on this type of mission and therefore it has not been possible to do such a mission yet.

With our telecom infrastructure still in its infancy on MARS, at the current state, alternatively a cooperative mission using a Lander/Rover as a robust local relay is described in this presentation.

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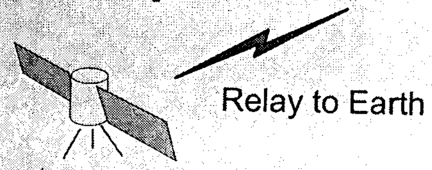
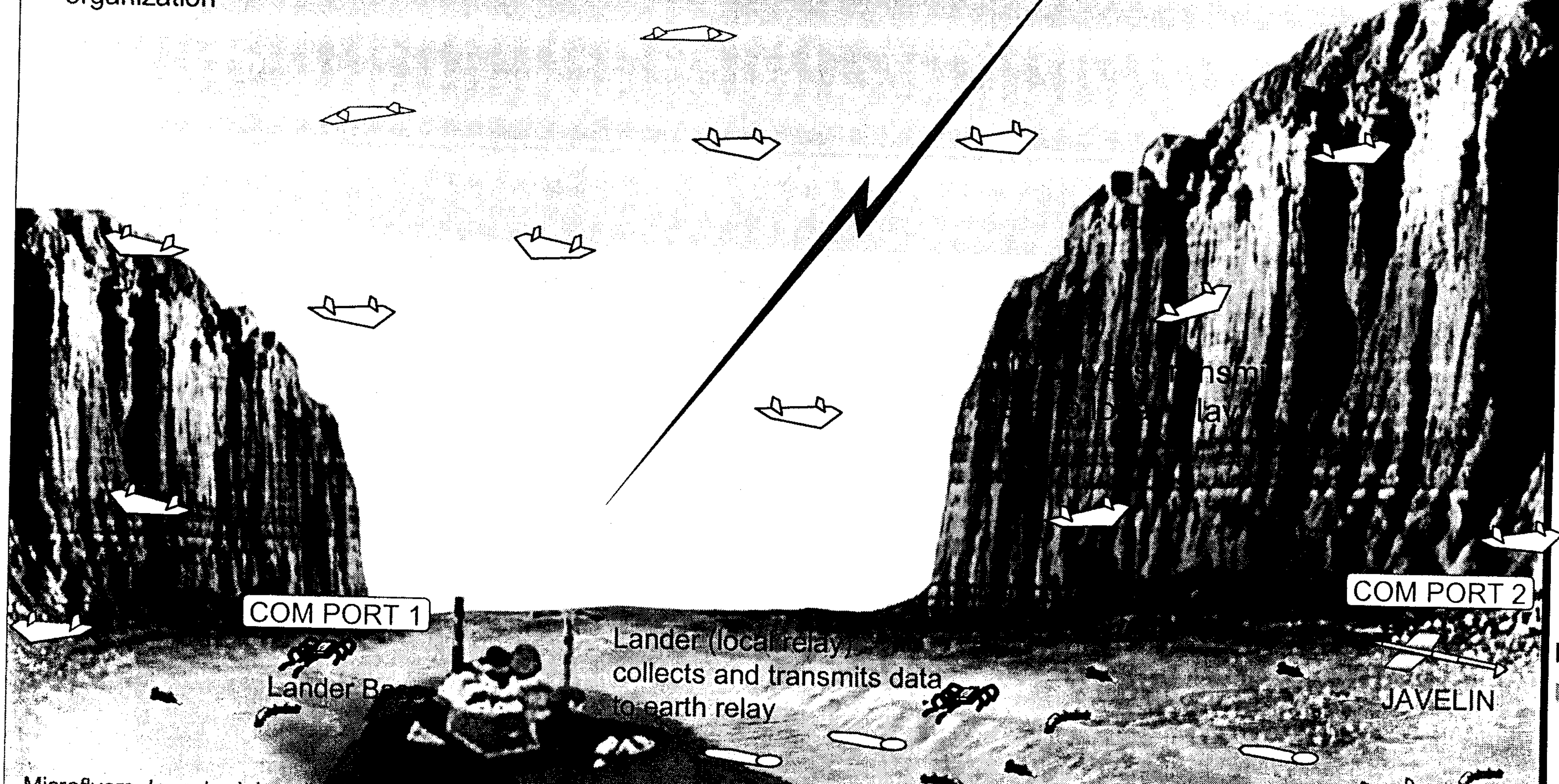
Cooperative Lander/Rover - Biomorphic Explorers MARS Missions

Microflyers launched off the lander or orbiter fly preset flight plans, based on the Sun position, to the targeted site. At the site they obtain close-up imagery, and/or deploy surface instruments/ explorers/ experiments. Dynamic routing of information in amorphous multi-hub ensemble by self - organization





Microflyers launched in coll[illegible] lander work in synergy with the surface /subsurface systems to enable new science endeavors. Lander provides a robust communication route for imagery down-link from the micro-flyer. Microflyers also deploy surface crawlers and subsurface explorers.

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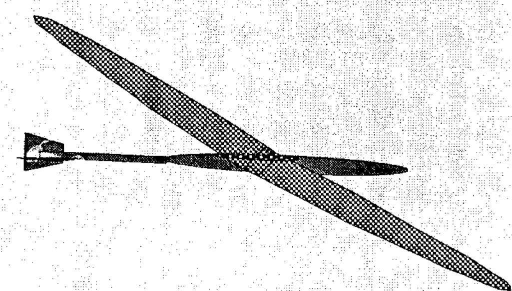
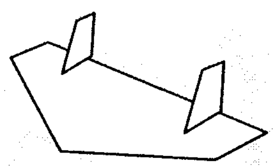
Biomorphic Microflyers

- Small, simple, low-cost system ideal for distributed measurements, reconnaissance and wide-area dispersion of sensors and small experiments.
- Payload mass fraction 50% or higher.
  - small mass (100 g - 1000 g)
  - low radar cross section
  - larger numbers for given payload due to low mass
  - precision targeting to destination
  - amenable to cooperative behaviors
  - missions can use potential energy by deploying from existing craft at high altitude
  - Captures features of soaring birds, utilizing rising currents in the environment
  - Launch options: spring, compressed gas launch, electric, rocket boosted etc
  - *Adaptive Control, Adaptive Wings*
  - *Self Repair features*





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Biomorphic Gliders

- **Small, simple, low-cost system ideal for reconnaissance and wide-area dispersion of sensors and small experiments.**
- **Payload mass fraction 50% or higher.**

Total Mass (M)	=	57	75	250	500 g
Payload (P)	=	32	45	150	300 g
P/M fraction	=	56	60	60	60 %
Wing Span	=	0.19	0.25	0.50	0.76 m
Wing Area	=	0.014	0.021	0.071	0.143 m^2
Volume	=	168	300	1700	5200 cm^3
Flight Speed	=	90	90	90	90 m/s
Range	=	50	55	72	83 km
Duration	=	590	650	800	1300 s
Glide Ratio	=	5.3	5.8	7.5	8.6
Starting Alt.	=	10	10	10	10 km

- Performance calculations based on conditions at 5 km altitude on Mars for a glider that has an analog 2gm camera
- Volume based on projected area x mean thickness x 1.2

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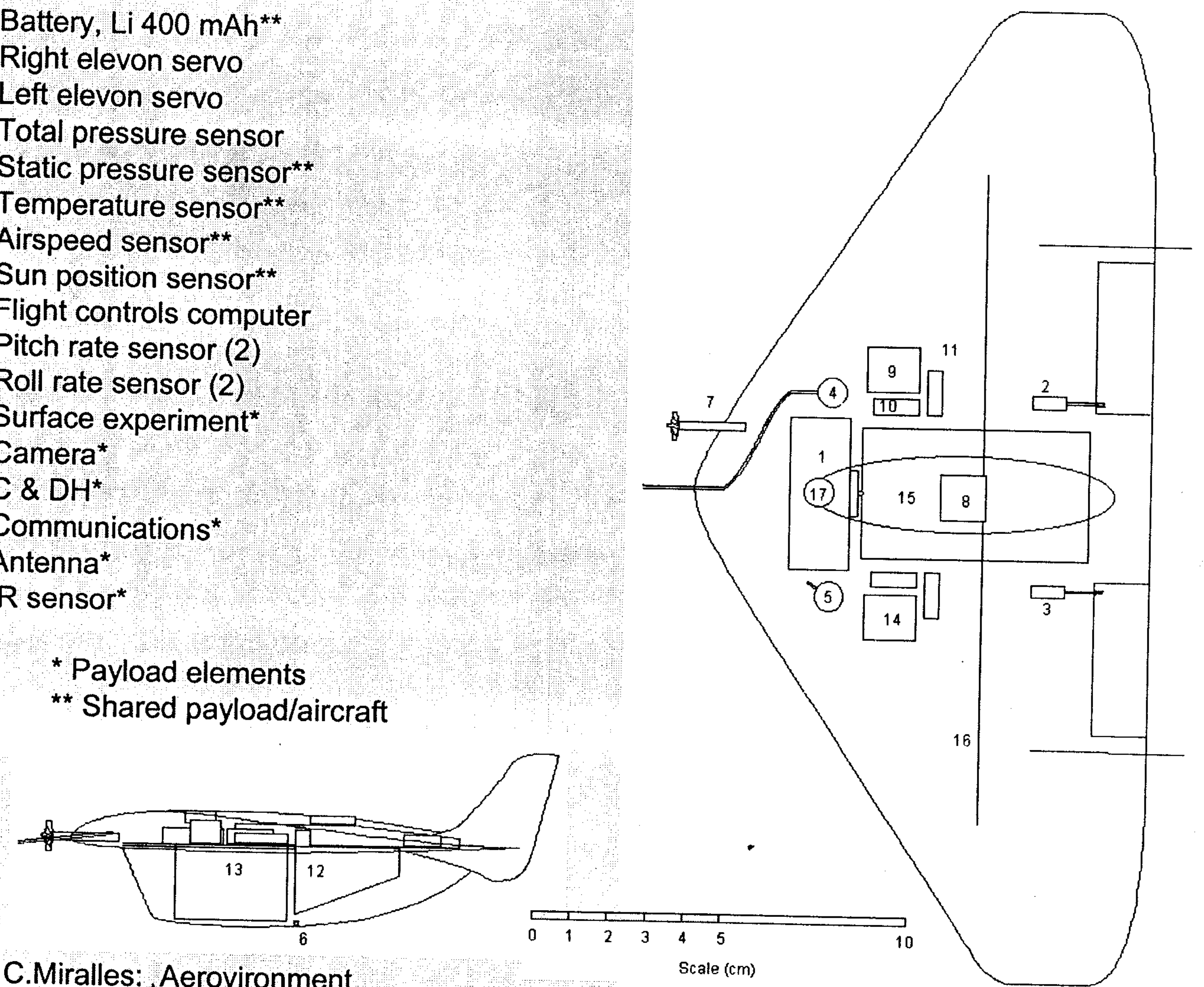
75 g Biomorphic Glider Internal Arrangement

- **System Components**
  1. Battery, Li 400 mAh**
  2. Right elevon servo
  3. Left elevon servo
  4. Total pressure sensor
  5. Static pressure sensor**
  6. Temperature sensor**
  7. Airspeed sensor**
  8. Sun position sensor**
  9. Flight controls computer
  10. Pitch rate sensor (2)
  11. Roll rate sensor (2)
  12. Surface experiment*
  13. Camera*
  14. C & DH*
  15. Communications*
  16. Antenna*
  17. IR sensor*

  * Payload elements
  ** Shared payload/aircraft



Designed by C.Miralles: Aerovironment

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75-g Biomorphic Glider Mass/Power Budgets

Item	Mass (g) Glider	Mass (g) Payload	Peak Power (W)	Average* Power (W)	Description
1 Battery	7.0	7.0	-	-	Li 400 mAh, LTC-311
2 Right elevon servo	0.5		0.200	0.200	AV experience, micro geared servos
3 Left elevon servo	0.5		0.200	0.200	
4 Total pressure sensor	1.5		0.010	0.010	IMMI IMP 2000
5 Static pressure sensor	1.5		0.010	0.010	IMMI IMP 2000
6 Temperature sensor		0.2	0.025	0.025	Si or Pt chip** [Iksan,Jumo]
7 Airspeed sensor	1.5		0.005	0.005	Servo motor/anemometer
8 Sun position sensor	1.0		0.005	0.005	Four-element photocell
9 Flight controls computer	1.0		0.050	0.050	AV experience, incl. some A-D conv.
10 Pitch rate sensor (2)	2.0		0.120	0.120	AV experience, Murata piezoceramic
11 Roll rate sensor (2)	2.0		0.120	0.120	
12 Surface experiment		10.0	10.000	0.050	Payload reserve***
13 Camera		20.0	0.250	0.050	JPL design, miniature camera
14 C&DH		2.0	0.050	0.050	Incl. some A-D conv. for science instr.
15 Communications		5.0	10.000	2.000	JPL/Caltech/AeroVironment design
16 Antenna		0.3	-	-	JPL/Caltech/AeroVironment design
17 IR sensor		0.3	0.200	0.200	***
18 Airframe/IC/Misc.	12.0		-	-	Composite/ribbon/misc.
Subtotal	30.5	44.8			
Total	**75.3**		**21.245**	**3.095**	

* *Average power consumed with duty cycle over 600 s flight.*
** *Data reflects device noted or next generation of device.*
*** *TBD*
Note: Battery mass shared between payload and glider systems.

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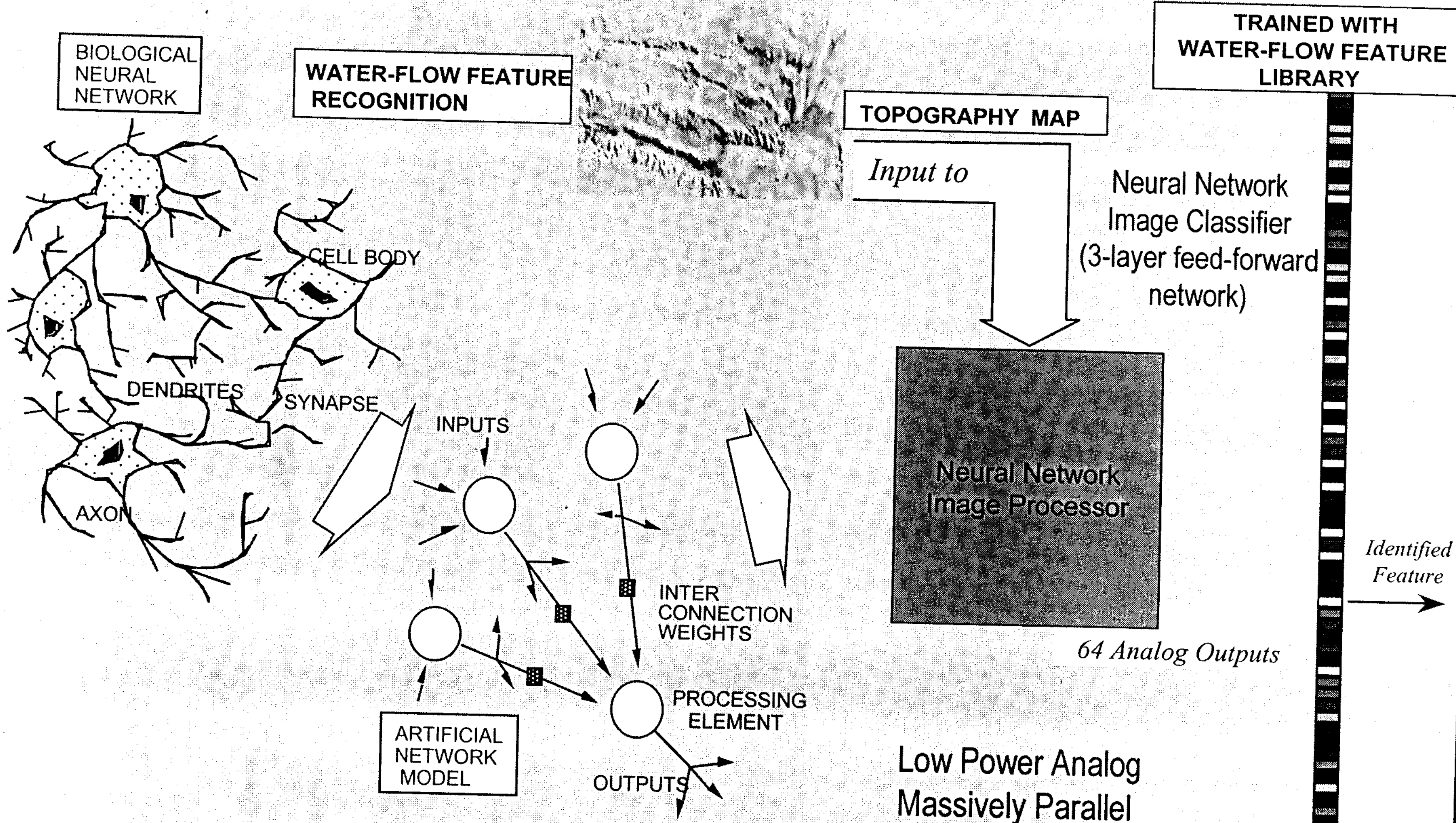
Enabling Processor for Landmark/Feature Recognition



- Low Power Analog
- Massively Parallel
- Bio-Inspired Processor

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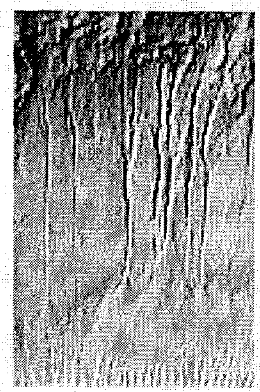
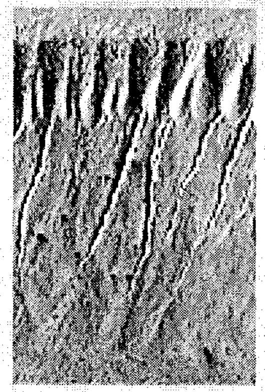
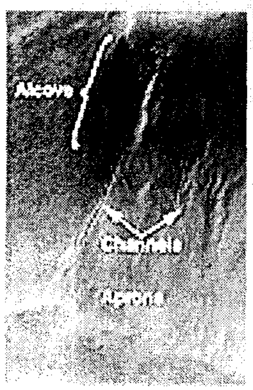
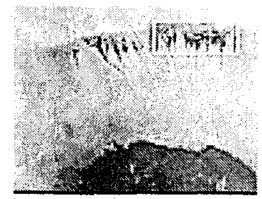
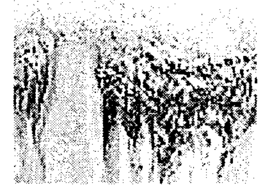
PRIORITIZED CATEGORIES OF WATER FLOW FEATURES

CLASS 1




CLASS 2


CLASS 3

SIMPLER CATEGORIES OF FEATURES

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PRIORITIZED CATEGORIES OF WATER FLOW FEATURES

CLASS 4

CLASS 5

COMPLEX CATEGORIES OF FEATURES

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Feature Recognition using Neural Networks

Neural networks enable autonomy in exploration missions by implementing an automatic feature identification and tracking ability. Automated target recognition in real environments is made difficult by variations in object size and orientation or environmental influence such as lighting or partial occlusion with another object. Specific characteristics of an object may be hard to express accurately with classic modeling. Neural networks can help, by learning from a library of examples of the object in different contexts, automatically capturing its key characteristics. There are two main characteristics of the approach presented here, one being the use of a mapping of theadapive size scanning/sliding window to a fixed size window and second the use of a neural network trained by backpropagation, which takes the fixed size window and recognizes whether it contains the desired feature or not. The approach is illustrated with a simuation demo, in which the neural network learned to recognized and lock-on craters during computer simulated imagery of a fly-by over Ganymede. The user just browses thru images and "shows the targets to the NN, by selecting them within a capturing window. "Negative" examples are also shown outside the target regions. A three-layer NN with sigmoidal neurons and trained by backpropagation with momentum learned the targets that the users has selected and detected them in the images usedfor training as well as in images never seen before. The inputs to the neural network were directly 8 bitgrey scale images and not feature vectors as in the majority of otherapporaches. To ensure a fixed number of inputs for the NN, we use an algorithm that lowers image resolution, from a variable size specified by the user in his selection, to a fixed size (here 16x16). The NN was a 256-32-2, the 2 output neurons being one for target and one for non-target, and with a winner-takes-all decision making procedure.

For recognition, an adaptive size window slides scanning the image, and is transformed in a fixed size window which is the input to the NN. The demo illustrates a fly-by over Ganymede, with targets being craters of various sizes. The NN is able to identify and track the craters while the camera moves over the surface. The processing structure may bemapped to a 3DANN stacked chip, which with the current algorithm would be able to process at a rate ofapproximately a few frames per second

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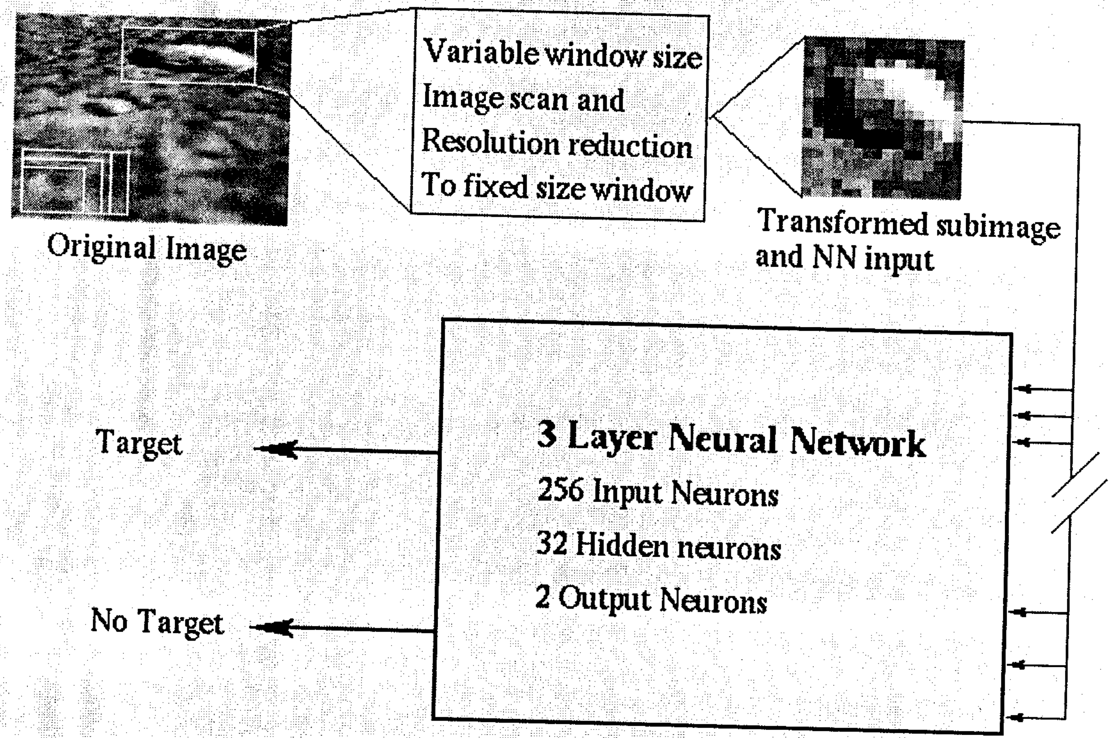
Feature recognition overview

Feature Recognition using Neural Networks



As illustrated above, each frame of the camera output is processed by the neural network to find targets, in this case craters. Variable sized subimages are extracted from the main image, converted to a fixed size and then fed to the neural 3-layer neural network which classifies the subimage as a feature or non-feature.

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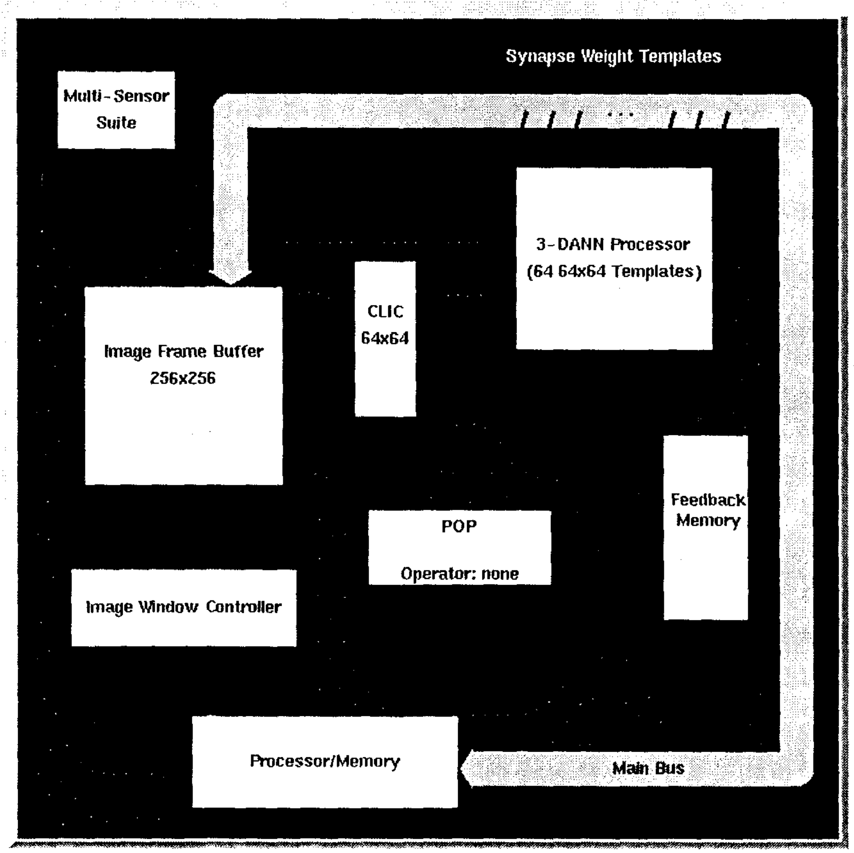
Feature Recognition using Neural Networks



In order to accomplish the recognitions at or near video frame rates, typical processors aren't enough. We must use custom hardware. The above diagram illustrates a possible way to utilize a 3 dimensional Neural Network architecture to do a highly parallel n-cubed inner product in a matter of a quarter of a microsecond with a point operation processor to do additional processing such as asigmoidal neuron or image manipulation.

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Crater recognition video

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- **ANALOG NEURAL THREE DIMENSIONAL PROCESSING EXPERIMENT**

FOR

- **REAL-TIME DETECTION, RECOGNITION, AND TRACKING OF TARGETS**
- **FROM FOCAL PLANE IMAGERY DATA WITH CLUTTERED BACKGROUND**

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JPL'S ANALOG SYNAPSE

JPL HAS DEVELOPED AN EXTREMELY FAST (~250 ns) ANALOG ULTRA LOW POWER (~3 μw), PROGRAMMABLE AND CASCADABLE CIRCUIT FOR A SYNAPSE

- A FAST 8 BIT DIGITAL MULTIPLIER MAY PERFORM THE SAME OPERATION IN A MATTER OF TENS OF NANOSECONDS
- HOWEVER, IT WOULD CONSUME SEVERAL TIMES MORE POWER AND OCCUPY MORE SILICON REAL ESTATE.

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JPL'S ANALOG SYNAPSE

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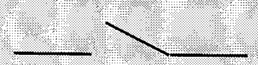
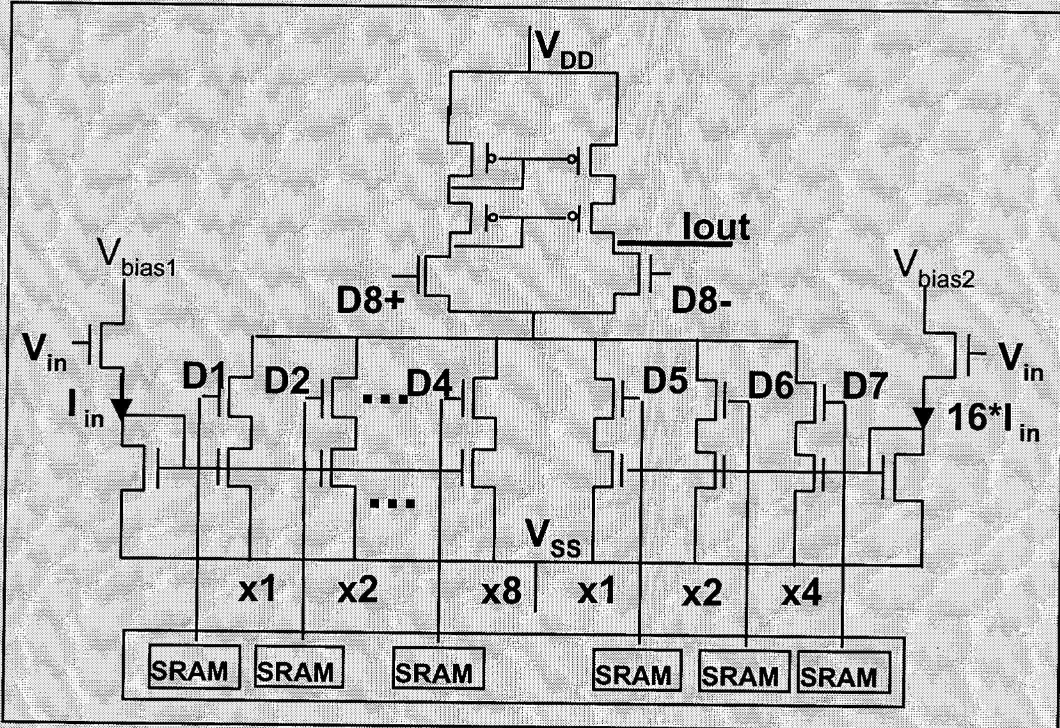
BINARY SYNAPSE



ANALOG SYNAPSE



- SRAM/MDAC DESIGN
- 8-BIT WEIGHT RESOLUTION
- LESS THAN 100 TRANSISTORS
- 1.2 μm FEATURE SIZE
- DIGITAL WEIGHTS ANALOG MULTIPLY

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SYNAPSE ARRAY ON THE NEURAL PROCESSING MODULE (NPM) CHIP

4096 MULTIPLY/ADD OPERATIONS PERFORMED IN ~250 ns ON THE NPM CHIP WITH THE 64X64 SYNAPSE ARRAY CONSUMING ONLY ~12mw OF POWER

- **IN A DIGITAL EMBODIMENT*, THE SAME OPERATION WOULD BE ACCOMPLISHED IN AS LITTLE AS ~ 400 ns**
- **HOWEVER, IT WOULD CONSUME ~ 80 w OF POWER.**

* CNAPS 512 PARALLEL PROCESSOR BOARD

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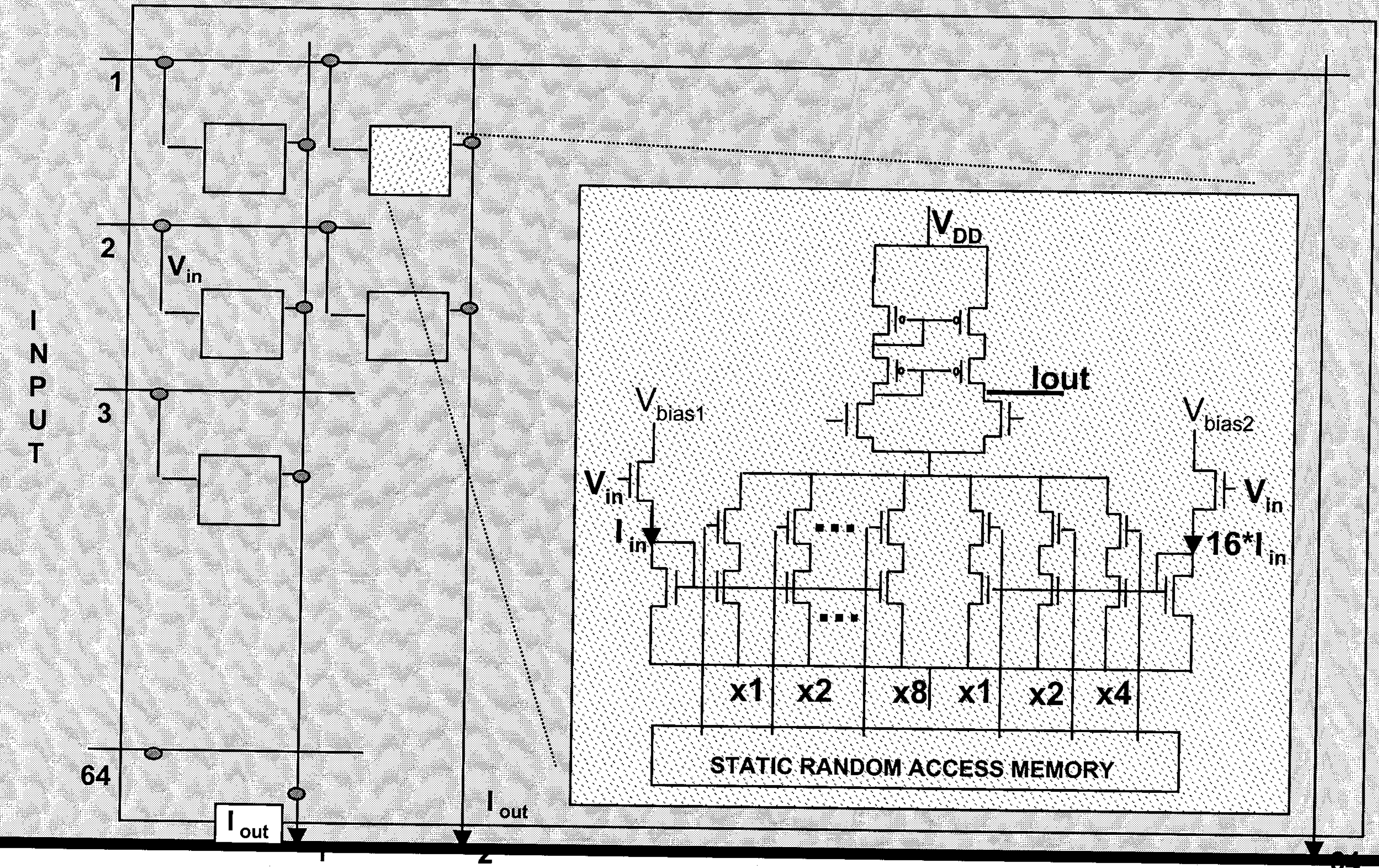
SYNAPSE ARRAY

CASCADED SYNAPSE CELLS FORM SYNAPSE ARRAY FOR MULTIPLY/ACCUMULATE IN A FULLY PARALLEL ARCHITECTURE



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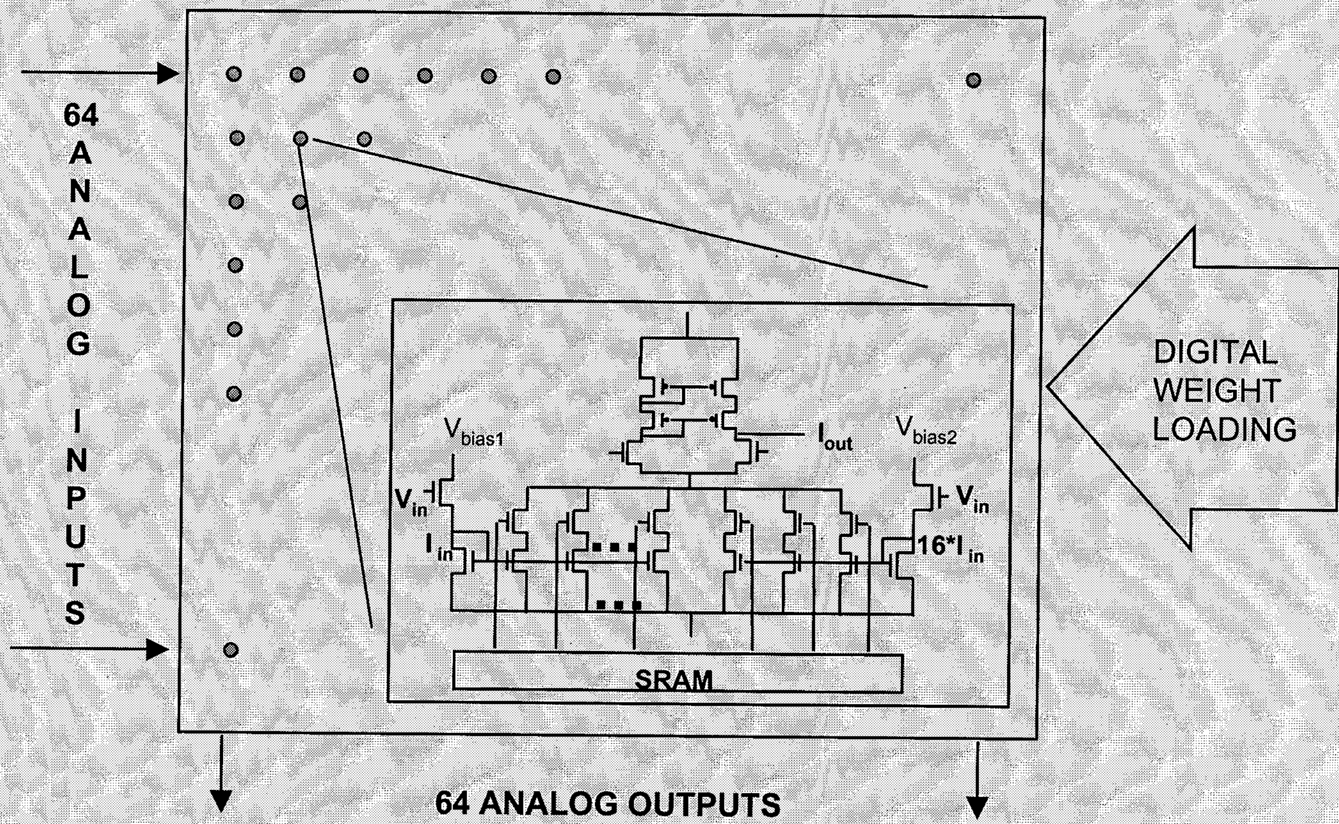

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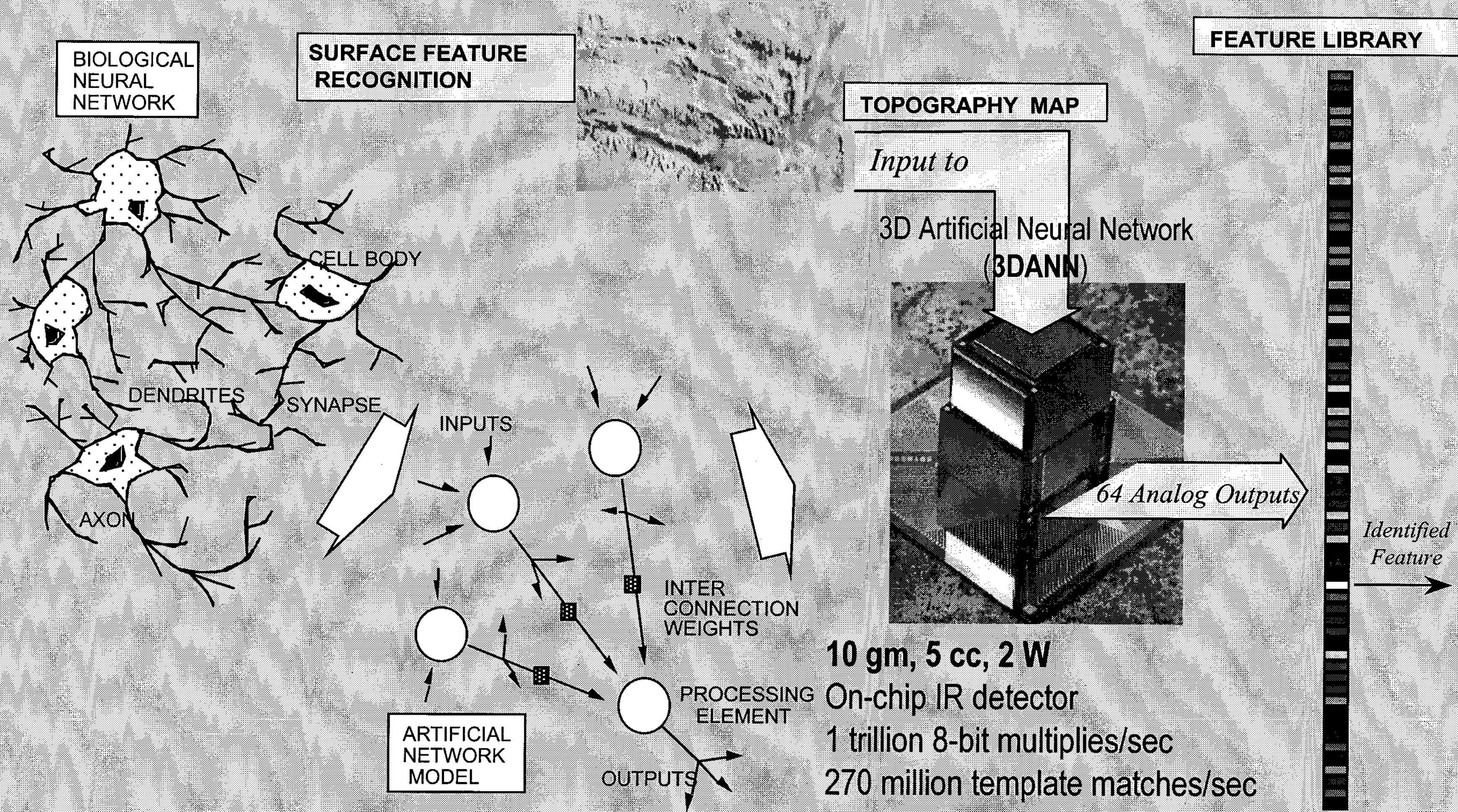
Enabling Processor for Surface Feature Recognition



10 gm, 5 cc, 2 W
On-chip IR detector
1 trillion 8-bit multiplies/sec
270 million template matches/sec
Compute power greater than fast supercomputer

JPL neural network chip design enables the 3DANN technology that delivers unprecedented processing speed for feature recognition ***(64 convolutions of 64x64 masks in 16 msec vs. 2 hours on state-of-the-art workstations)***

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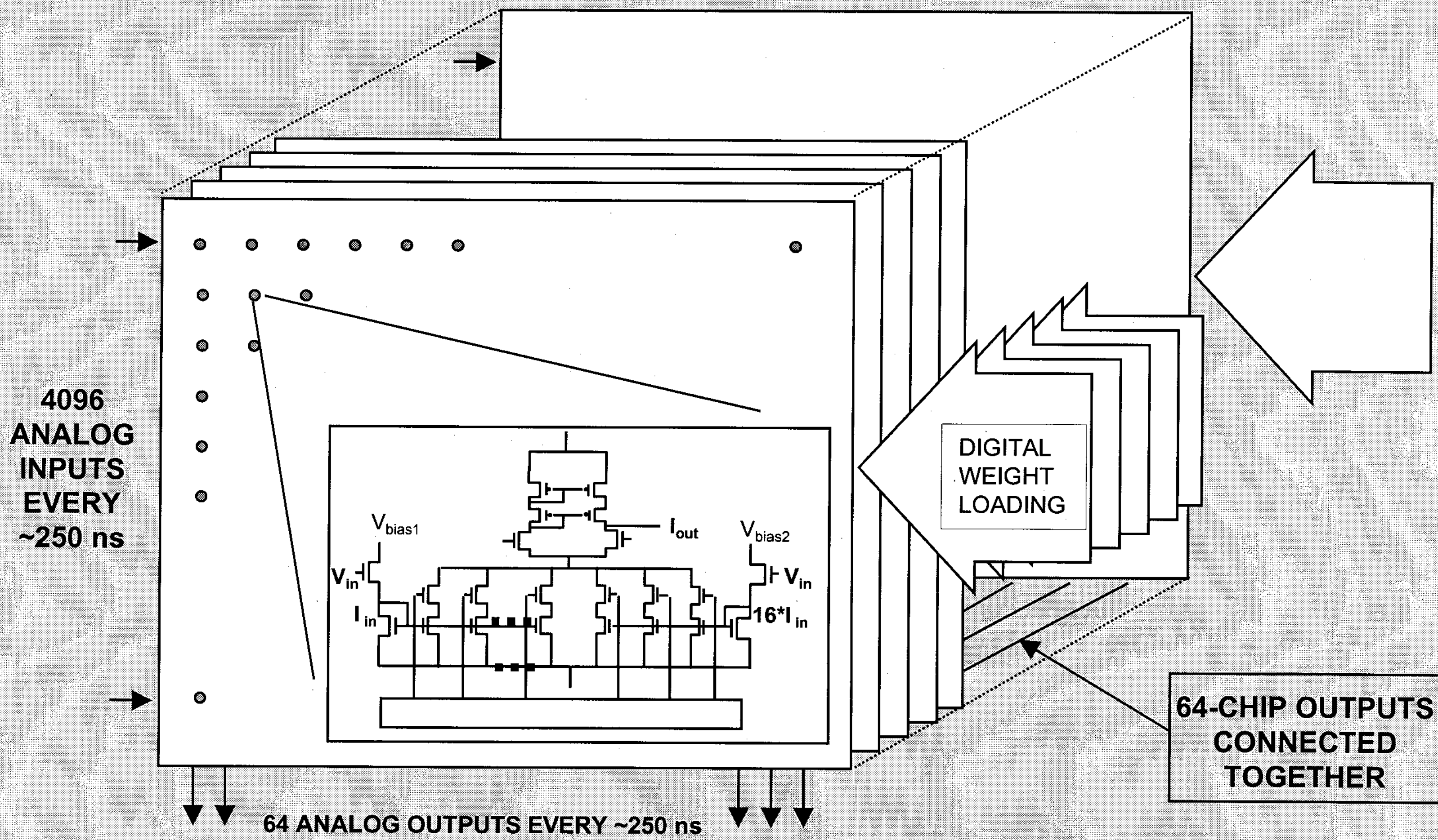
NPM CUBE

WHEN STACKED, THE NPM CUBE WILL PERFORM ~262,000 MULTIPLY AND ADD OPERATIONS IN ~250ns CONSUMING ~0.8 w OF POWER



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PARALLEL IMAGE INPUT TO NPM CUBE

A BREAK-THROUGH CIRCUIT HAS BEEN DEVELOPED AT JPL FOR HIGH SPEED (~250 ns) IMAGE DATA INPUT TO THE NPM CUBE

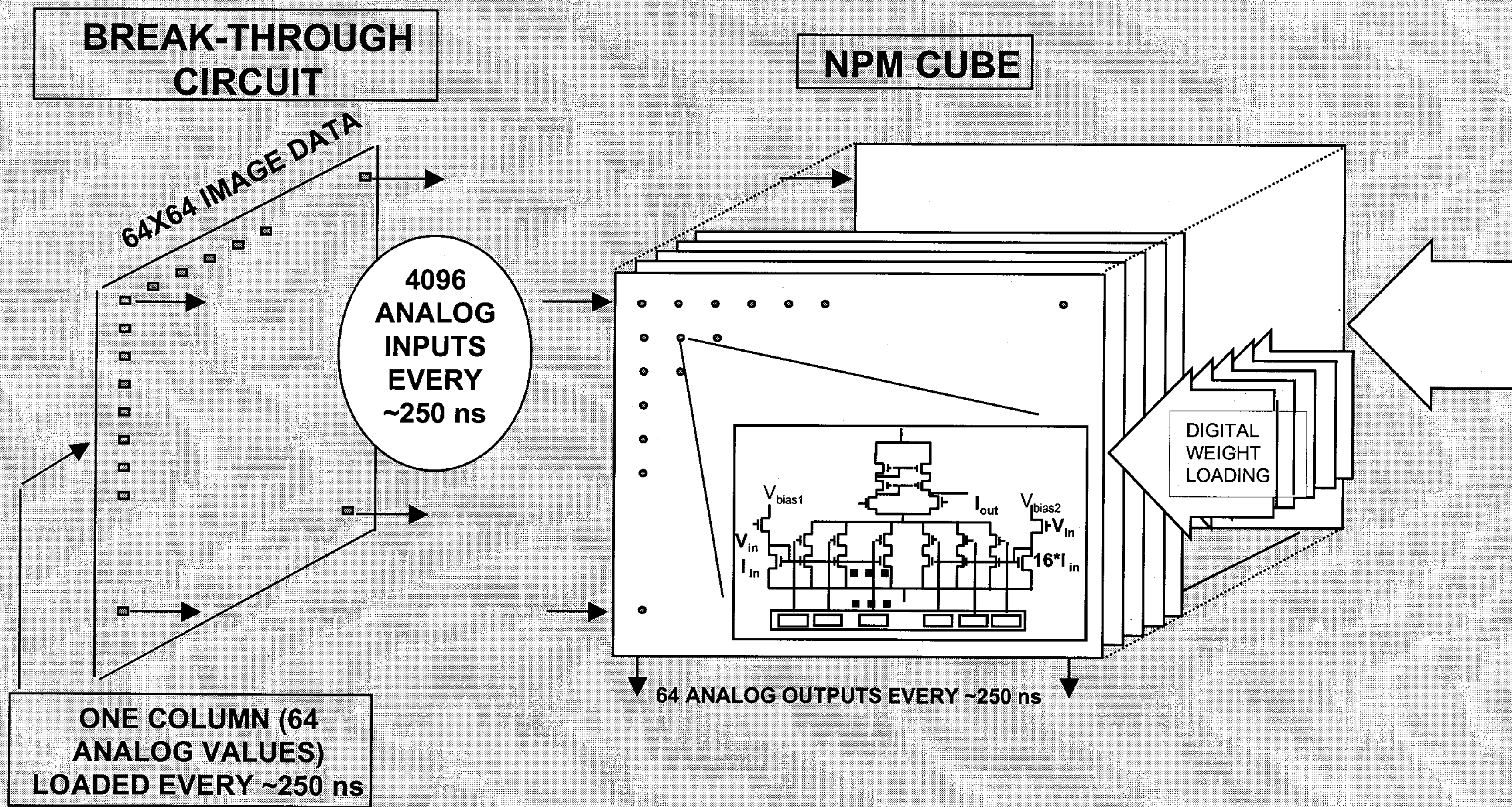

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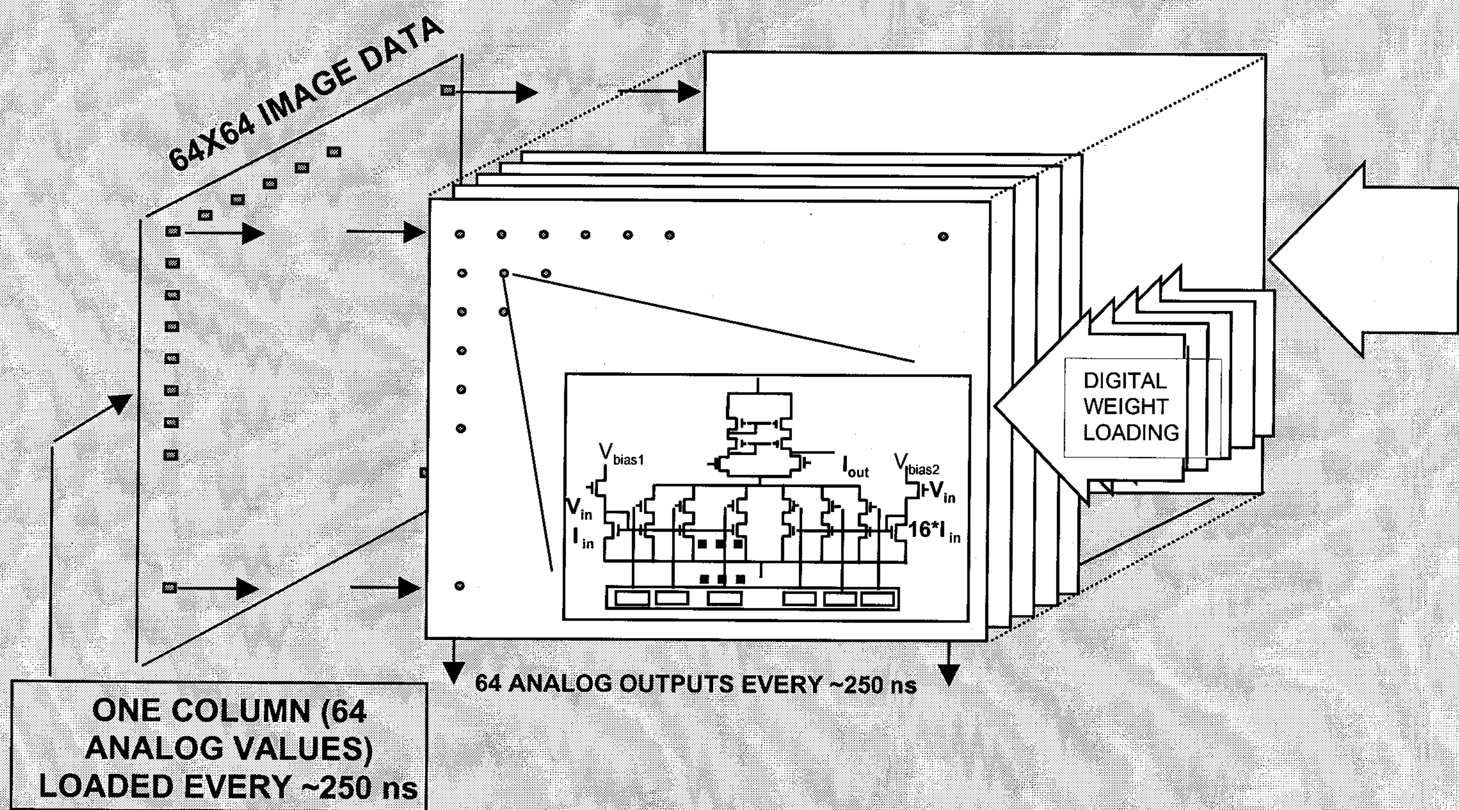
IMAGE INPUT CHIP FOR NPM CUBE

THIS CIRCUIT, FOR THE FIRST TIME, PROVIDES HIGH SPEED (~250 ns) IMAGE DATA (64X64) INPUT TO THE NPM CUBE FROM VIRTUALLY ANY SIZE & TYPE OF SENSOR ARRAY



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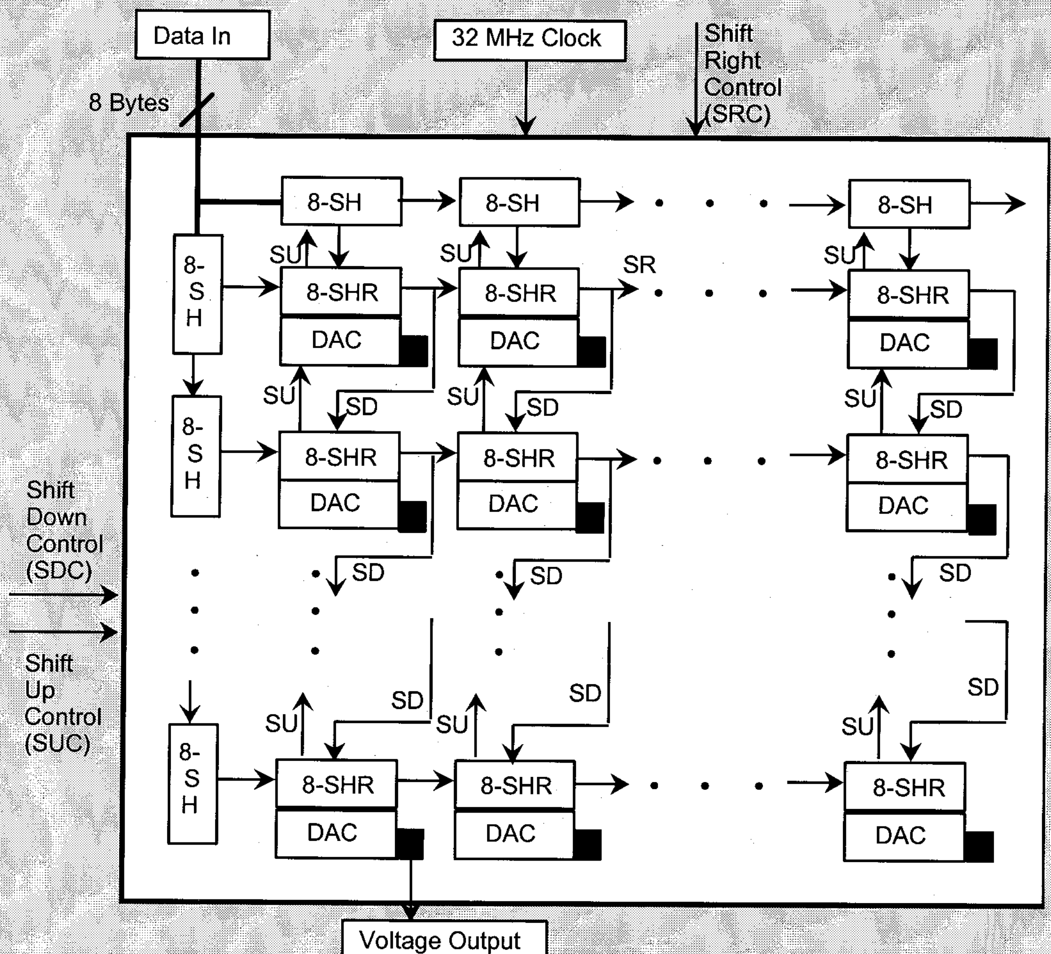
COLUMN LOADING INPUT CHIP (CLIC)

64-PIXEL COLUMN ADDED TO THE PREVIOUS 63X64 IMAGE SEGMENT PROVIDES A 64X64 PARALLEL INPUT TO NPM CUBE EVERY ~250 ns



- ONE CONTIGUOUS- COLUMN DATA IS LOADED TO CLIC EVERY ~250 ns
- LAST CONTOGUOUS COLUMN OF THE PREVIOUSLY LOADED DATA IS REJECTED OUT
- CONTIGUOUS ROW LOADING IS IDENTICALLY ACHIEVED
- 4096 PIXEL DATA IS THUS FED TO NPM CUBE EVERY ~250 ns

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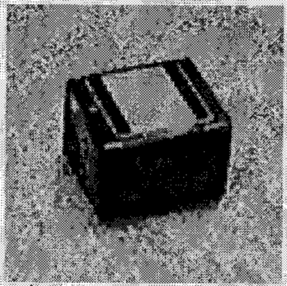
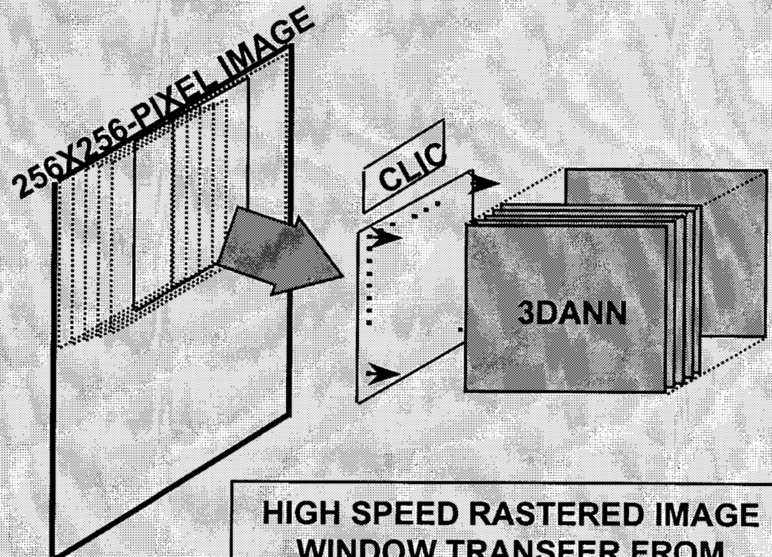
Enabling Processor

3DANN-Modified

Ultrafast Inner-Product/Convolution Engine



64 convolutions of 64x64 masks in 16 msec (vs. 2 hours on state-of-the-art workstations)



- AN INNOVATIVE COLUMN LOADING INPUT CHIP (CLIC) REPLACES THE 64X64-PIXEL IR SENSOR ARRAY OF 3DANN
- RASTERED 64X64 WINDOW OF A LARGER IMAGE FROM ANY TYPE OF SENSOR ARRAY IS FED-IN AS INPUT TO 3DANN FOR REAL TIME PROCESSING

HIGH SPEED RASTERED IMAGE WINDOW TRANSFER FROM IMAGE BUFFER TO 3DANN

3DANN-M represents a general-purpose ATR computer capable of accepting image data acquired from any size and type of sensor array.

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PROCESSING SPEED COMPARISON

	SIMULANTE ON SUN SPARC 10	COTS CUSTOM DSP SOLUTION	**3DANN Hardware**
APPROX. SPEED	~10^7 OPS/s	~10^{10} OPS/s	~10^{12} OPS/s
CONVOLUTION 256X256 IMAGE 64X64 TEMPLATE 64 TEMPLATES	2.8 h	1 s	16 ms
CLASSIFICATION 3 LAYER FEED FORWARD NEURAL NETWORK	> 3 h	1.2 s	16 ms

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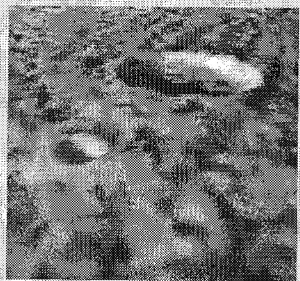
Enabling Methodology for ATR

Input Image



Object Learning and Recognition System

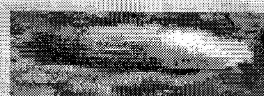
PRESENTED OBJECT

CLASS Flow Crater

ORIENTATION Θ Φ

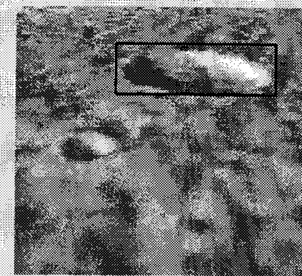
SCALE X Y

RECOGNITION



OBJECT RECOGNIZED

Output Image



Hierarchical learning and recognition is AN EXCELLENT APPROACH to efficiently achieve Detection through "Precision Tracking," and 3DANN enables the implementation of this ATR in real-time.

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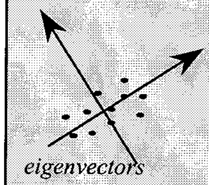
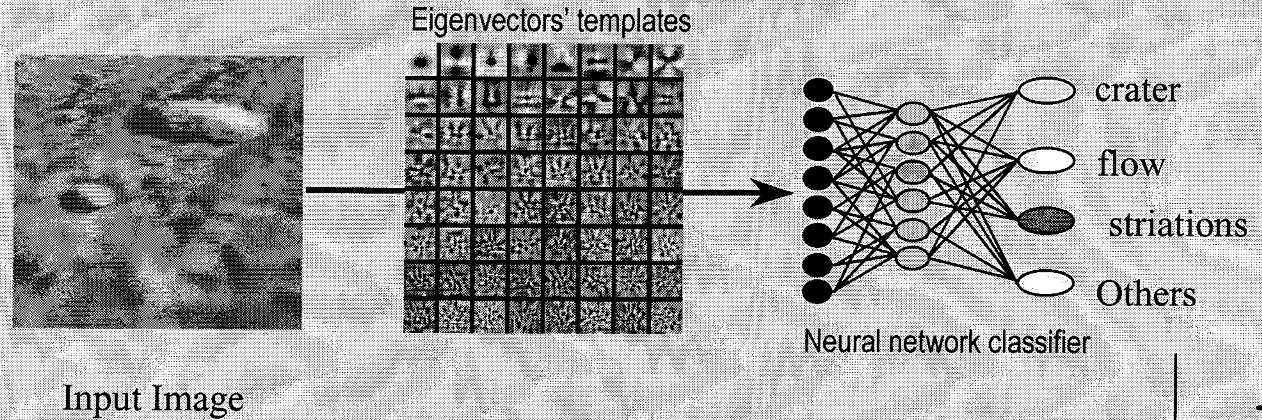
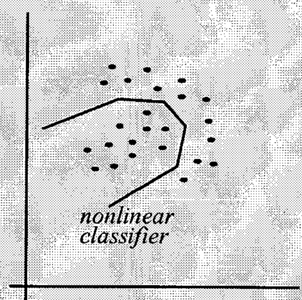
Enabling Methodology



Eigenvectors provide an effective/efficient description of data points in a multi-dimensional space.



Neural networks are uniquely suited for solving nonlinear problems.



Two powerful mathematical paradigms (eigenvectors and neural networks) are used in combination to solve real-time ATR problems.

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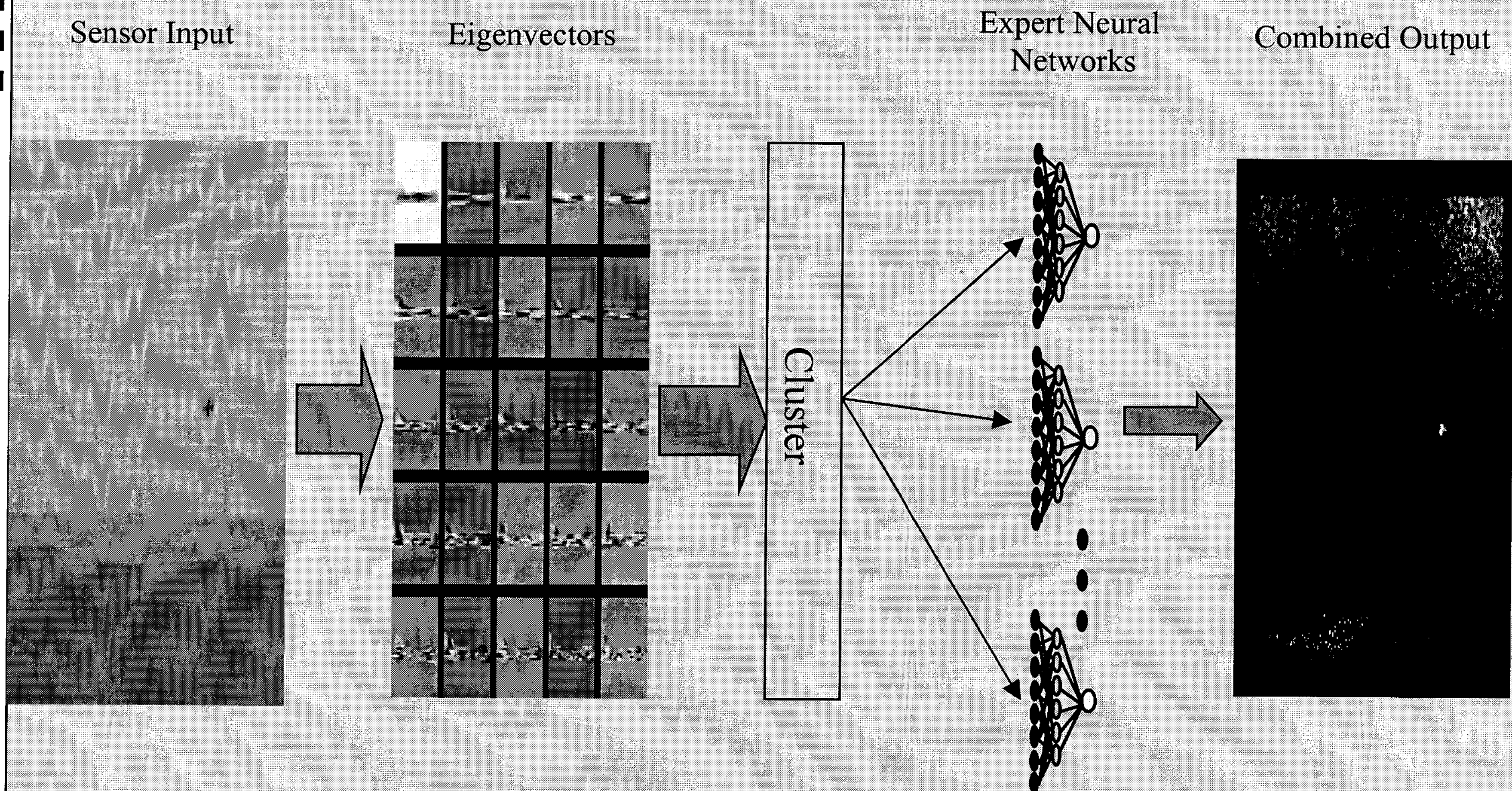
Target recognition methodology



Using neural network classifiers on Eigenvector projections to recognize/identify targets of various lighting conditions, scales and orientations.

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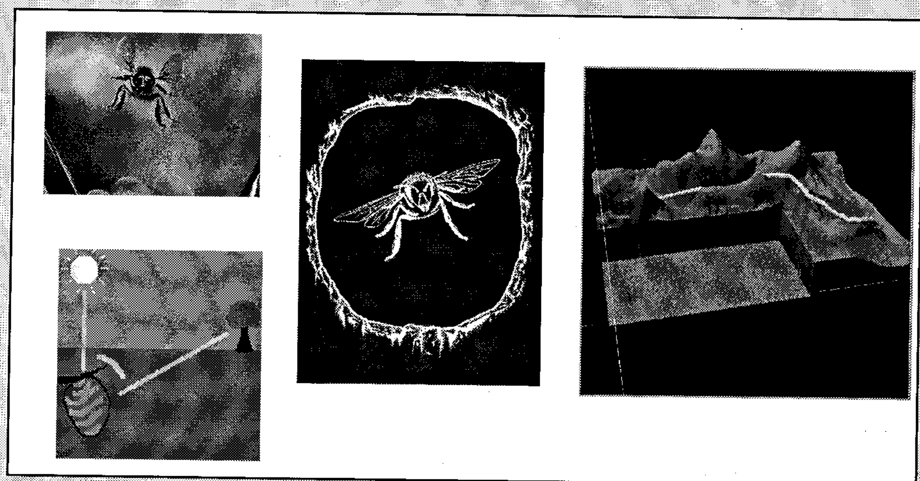
Biomorphic Navigation

Insects (for example honey bees) cope remarkably well with their world, despite possessing a brain that carries fewer than 0.01% as many neurons as ours does. Although most insects have immobile eyes, fixed focus optics(no range info) and lack stereo vision, they use a number of ingenious strategies for perceiving their world in three dimensions and navigating successfully in it. Our intent is to distill some of these ‘bee’ inspired strategies to obtain unique solutions to navigation and landing and explore the feasibility of incorporating these success strategies in our microflyers for future missions



Karl von Frisch, 1965
Wehner and Rossel, 1985
Barbara Shipman, 1997
Srinivasan et al, 2000, 1997

Honeybee Inspired landing, terrain following, gorge following, obstacle avoidance and point-to-point navigation

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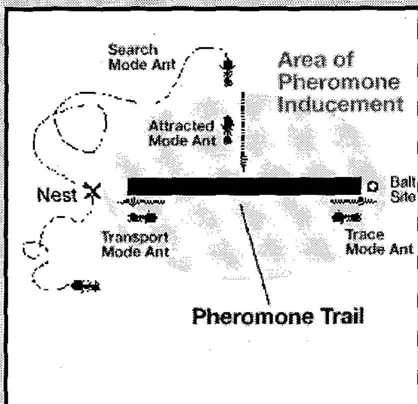
Biomorphic Cooperative Behaviors

The behavior of ant colonies, specifically, how the ants coordinate complex activities like foraging and nest building, has fascinated researchers in ethology and animal behavior for a long time. Several behavioral models have been proposed to explain these capabilities. Algorithms inspired from the behavior of ant colonies have already entered into the mathematical field of multi-parameter optimization. Solar system exploration, particularly of Mars and certain planet/satellites, could be substantially enhanced through use of a multitude of simple, small, somewhat autonomous explorers that as a group would be capable of "covering" large areas. A fleet of such explorers would have some form of limited communication with a mother ship (a larger lander/rover or an orbiter). In many cases, cooperation among all the "fleet-mates" could greatly enhance group effectiveness. Our concept is geared to identify potential useful cooperative behaviors for such explorers by surveying emerging multirobot-multiagent techniques and by assessing some of the uniquely powerful examples of cooperative behavior and self-organization observed in nature, specifically in the insect kingdom.

Insects Operating Cooperatively



(A) Behavior of each ant.

Nakamura and Kurumatani, 1995
Kubo, 1996

Ants' elaborate communication method with pheromone trails

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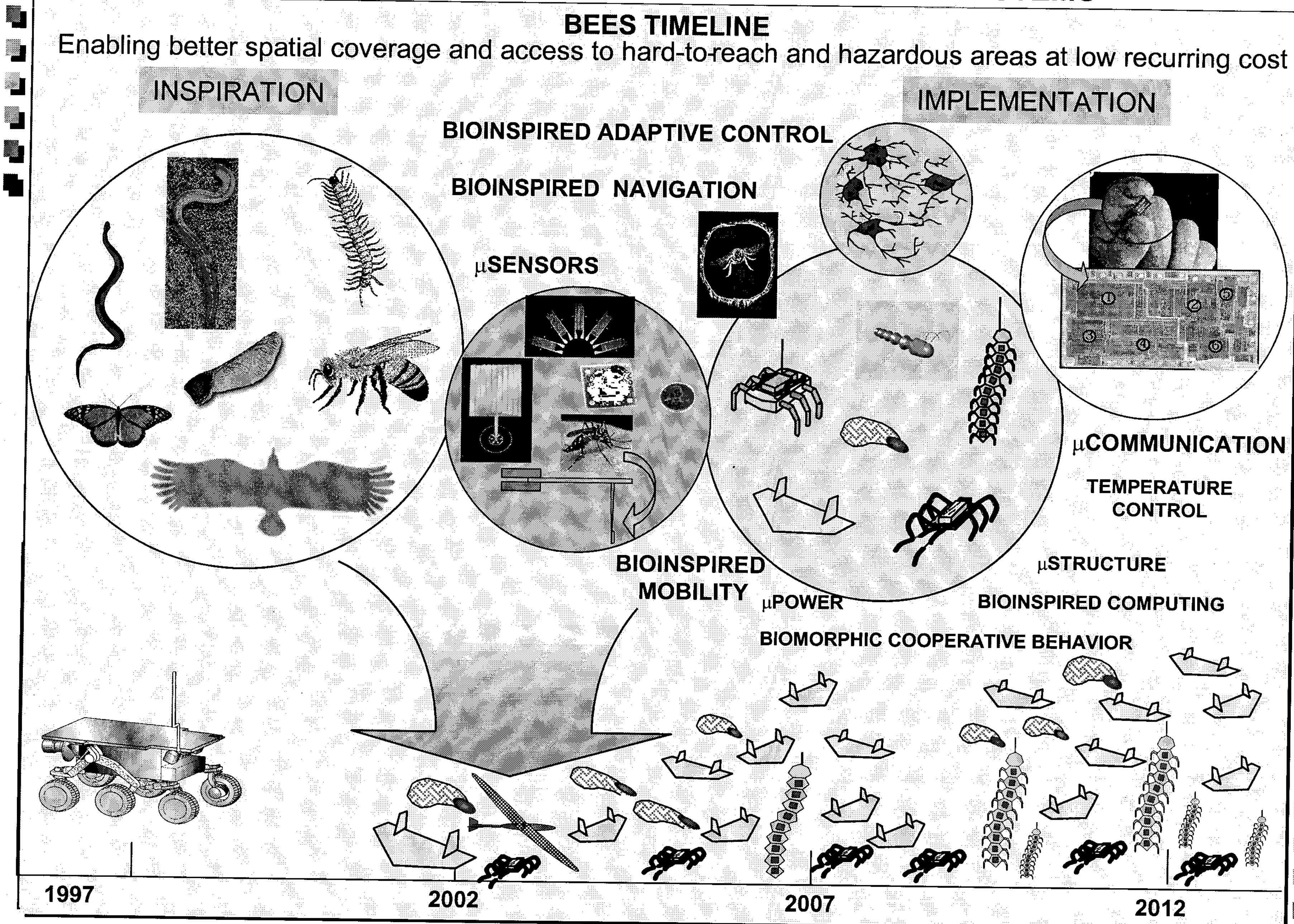
BIOINSPIRED ENGINEERING OF EXPLORATION SYSTEMS



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Biomorphic Mission: Cooperative Lander/Rover - Biomorphic Explorers- Time Step 1

TECHNOLOGY HIGHLIGHTS:

- TWO COMPORT(LANDER AND JAVELIN), LOCAL TELECOM RELAYS ALLOW
  - ROBUST TELECOM BASE
  - DIFFERENTIAL POSITIONING
- SURFACE LAUNCHED EXPLORER ALLOWS SELECTION OF TIMING OF TASK
- ON CALL USE OF LAUNCHED EXPLORERS ALLOWS MULTIPLE TRIES FOR SAME OR DIFFERENT TARGETED LOCATIONS
- DIRECTED TRAVEL FOR CLOSE-UP IMAGING
- TARGETED DEPLOYMENT OF IN-SITU EXPERIMENT, INSTRUMENT OR OTHER EXPLORERS (crawlers, hexapods, snakebots, wormbots)

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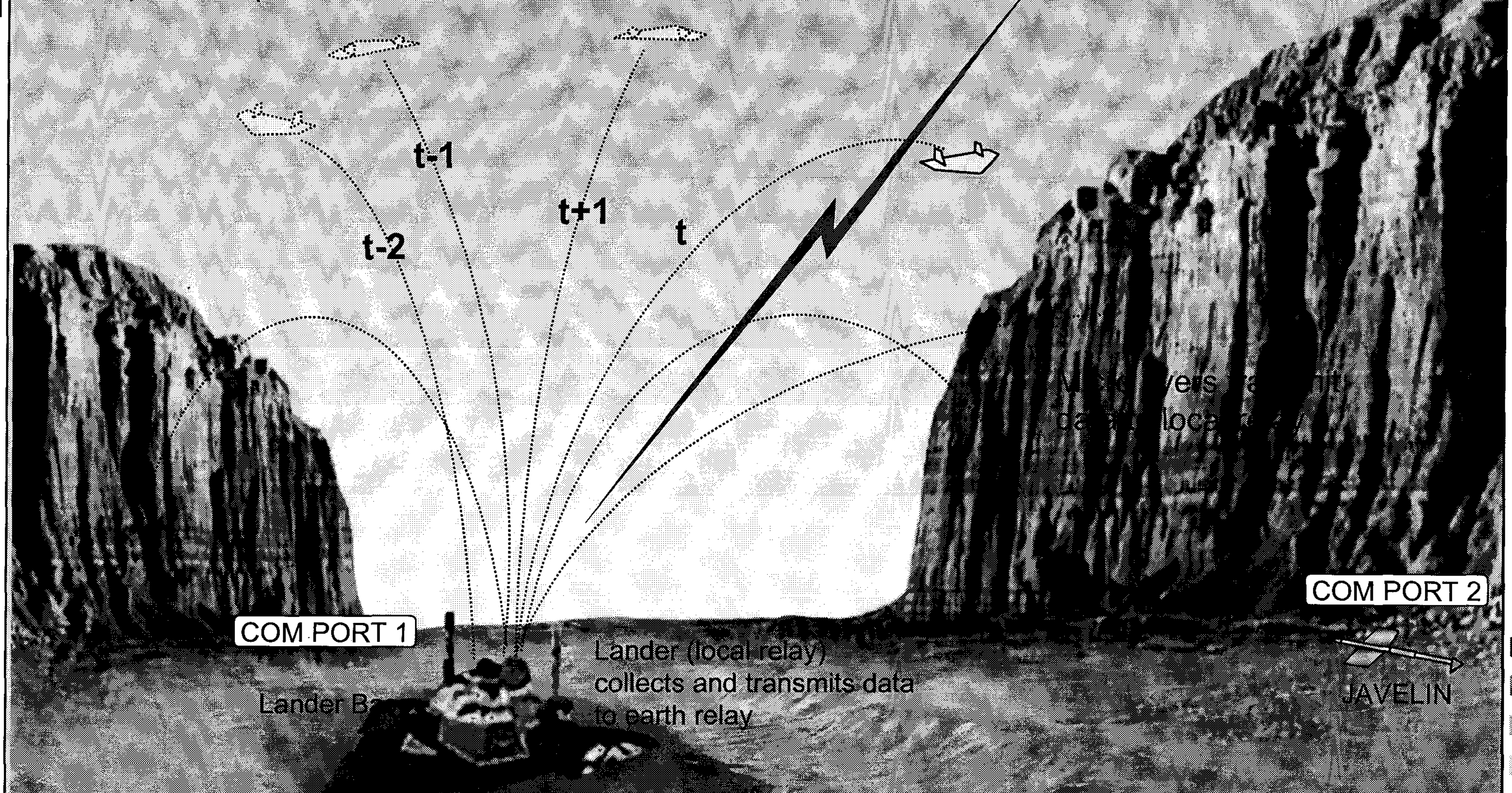
2007 Biomorphic Mission: Cooperative Lander/Rover - Biomorphic Explorers

On -call Microflyers launched off the lander, one at a time to fly to targeted location and perform close-up imagery, and/or deploy surface instruments/ explorers/ experiments



Microflyers launched, in collaboration with the lander, work in synergy with the surface /subsurface systems to enable new science endeavors. Lander provides a robust communication route for imagery down-link from the micro-flyer. Microflyers can also deploy surface crawlers and subsurface explorers.

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Biomorphic Mission - Time Steps

- Near Term 2007 (Time Step 1)
  - Image surface topography
  - Characterize terrain around lander
  - Identify rocks of interest for rover/lander
  - Distribution of Instruments/Experiments/Surface explorers to targeted sites
- 2007 - 2009 (Time Step 2)
  - Enable scouting, long range maps of areas of interest, and distributed deployment/in-situ measurements
  - Communication based on a self-organized, self-routing network, which is optimized dynamically using amorphous network of multiple hubs.
- Long Term 2011 and beyond (Time Step 3 & 4)
  - Co-operative Operation of a multitude of Explorers together to obtain imagery, and deploy surface payloads, Reconnaissance Mission
  - Astronaut Launched Microflyers: empowering the human to obtain extended reach and sensory acquisition capability from locations otherwise hazardous/inaccessible (JSC synergistic interest)
  - Robonaut/Centaur Launched Biomorphic Explorers (JSC synergistic interest)

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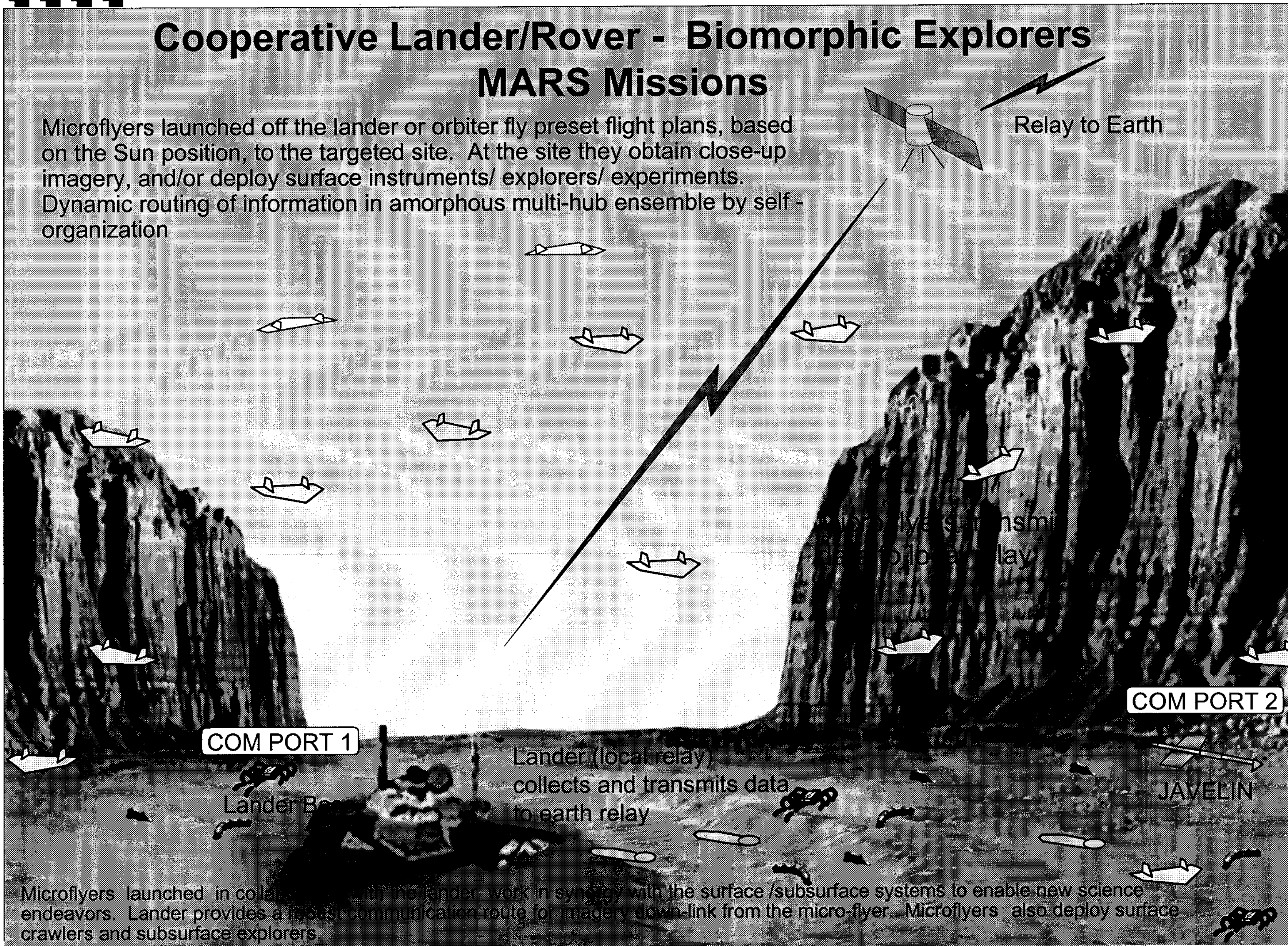

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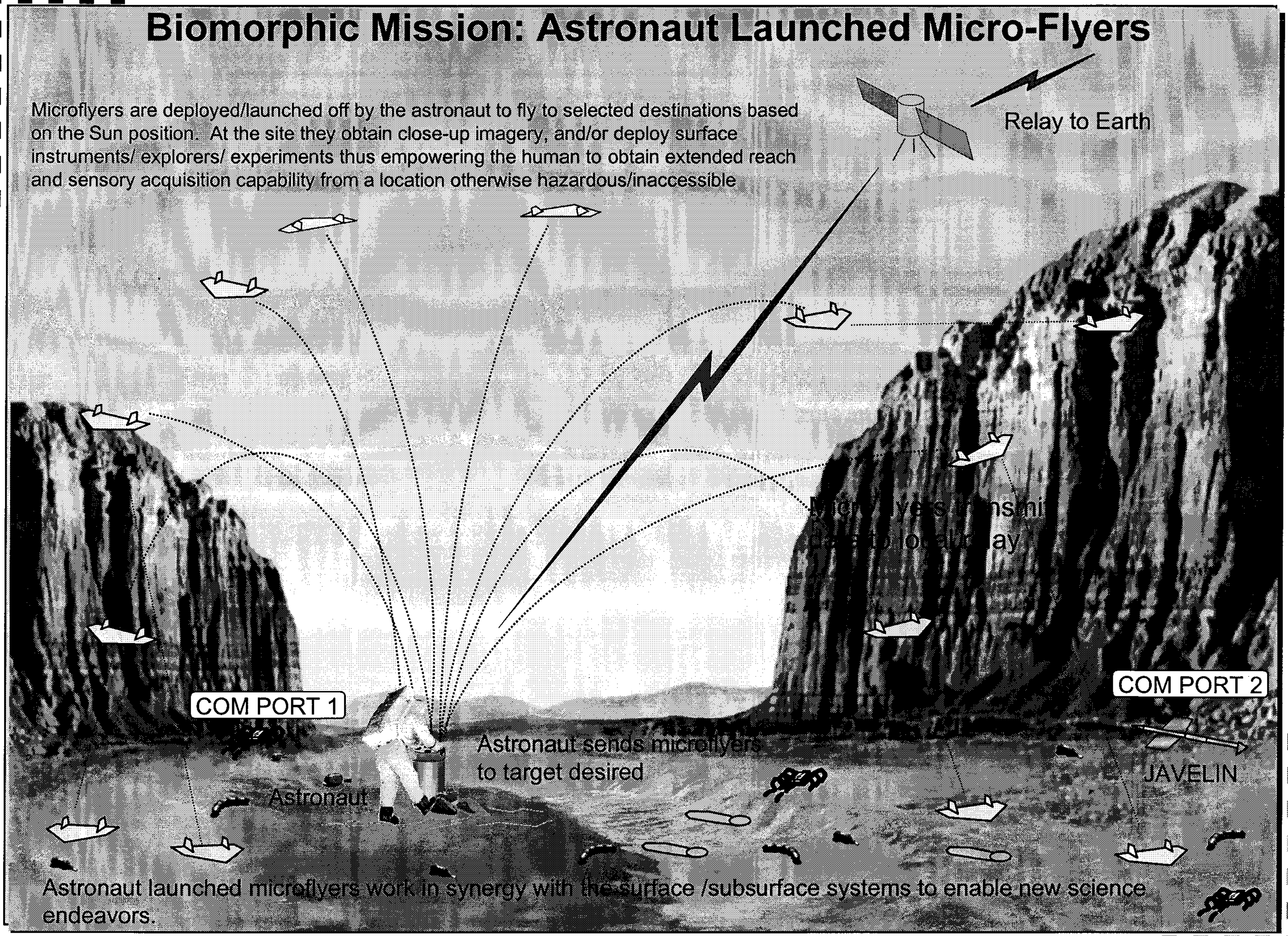

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Science Applications

... WHICH WOULD BE ENABLED/ENHANCED BY SUCH EXPLORERS.....

- VALLES MARINERIS EXPLORATION
  - ONE SINGLE SITE RICH IN GEOLOGIC UNITS
  - STUDY STRATIGRAPHIC COLUMN TOP TO BOTTOM ALONG THE CANYON WALL
  - OPTIMUM SCIENCE SAMPLE SITE

  ... imager, temperature sensor, pressure sensor, sniffer: e-nose, individual gases, elements, etc.

- SCOUTING FOR CONDITIONS COMPATIBLE WITH LIFE TO LEAD US TO THE SPOTS THAT MAY HOLD SAMPLES OF EXTINCT/EXTANT LIFE
  - WIDE-AREA SEARCH WITH INEXPENSIVE EXPLORERS EXECUTING DEDICATED SENSING FUNCTIONS: close-up imaging!!!!

  ... Individual gases, sniffer: e-nose, chemical reactions, pyrotechnic test, elements, specific amino acids, signatures of prebiotic chemistry, etc.

- GEOLOGICAL DATA GATHERING:
  - DISTRIBUTED TEMPERATURE SENSING
  - SEISMIC ACTIVITY MONITORING
  - VOLCANIC SITE

  ... Multitude of explorers working in a cascade or daisy-chain fashion cooperatively to fulfill task

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Applications (Dual Use NASA & DoD)

- Close-up Imaging, Site Selection
- Meteorological Events: storm watch
- Reconnaissance
- Biological Chemical ~~Warfare~~ Sensing
- Search and Rescue etc.
- Surveillance
- Jamming

- Distributed Aerial Measurements
  - Ephemeral Phenomena
  - Extended Duration using Soaring

- Delivery and lateral distribution of Agents (sensors, surface/subsurface crawlers, clean-up agents

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Biomorphic Missions

- **PAYOFF:**
- **MULTIPLE USE NASA/DoD/NIH/NCI**
- BIOMORPHIC EXPLORERS, IN COOPERATION WITH CURRENT EXPLORATION PLATFORMS CAN ENABLE
  - EXPLORATION OF CURRENTLY INACCESSIBLE AND/OR HAZARDOUS LOCATIONS
  - MUCH BROADER COVERAGE OF EXPLORATION SITES
  - EXPLORATION AT LOWER COST
- MINIATURIZED MICRO/NANO BIOMORPHIC EXPLORERS CAN BE USED FOR DETECTION/DIAGNOSIS/TREATMENT OF DISEASES AND AILMENTS OF HUMAN BODY NON-INVASIVELY AT LOW COST

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